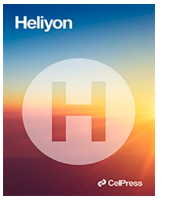
Heliyon 9 (2023) e17591

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Effects of renal denervation on cardiac function after percutaneous coronary intervention in patients with acute myocardial infarction☆

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ARTICLE INFO

Keywords:
Acute myocardial infarction
Renal denervation
Sympathetic nervous system
Cardiac function
Arrhythmia

ABSTRACT

Objective: To observe the effect of renal artery denervation (RDN) on cardiac function in patients with acute myocardial infarction after percutaneous coronary intervention (AMI-PCI).
Methods: This is a single-centre, prospective randomized controlled study. A total of 108 AMI-PCI patients were randomly assigned to the RDN group or the control group at 1:1 ratio. All patients received standardized drug therapy after PCI, and patients in the RDN group underwent additional RDN at 4 weeks after the PCI. The follow-up period was 6 months after RDN. Echocardiography-derived parameters, cardiopulmonary exercise testing (CPET) data, Holter electrocardiogram, heart rate variability (HRV) at baseline and at the 6 months-follow up were analyzed.
Results: Baseline indexes were similar between the two groups (all $P > 0.05$). After 6 months of follow-up, the echocardiography-derived left ventricular ejection fraction was significantly higher in the RDN group than those in the control group. Cardiopulmonary exercise test indicators VO_2Max, metabolic equivalents were significantly higher in the RDN group than in the control group. HRV analysis showed that standard deviation of the normal-to-normal R–R intervals, levels of square root of the mean squared difference of successive RR intervals were significantly higher in the RDN group than those in the control group.
Conclusions: RDN intervention after PCI in AMI patients is associated with improved cardiac function, improved exercise tolerance in AMI patients post PCI. The underlying mechanism of RDN induced beneficial effects may be related to the inhibition of sympathetic nerve activity and restoration of the sympathetic-vagal balance in these patients.

☆ ☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

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https://doi.org/10.1016/j.heliyon.2023.e17591
Received 15 May 2023; Received in revised form 21 June 2023; Accepted 21 June 2023
Available online 5 July 2023

1. Introduction

Mortality and morbidity rates of acute myocardial infarction (AMI), a type of cardiovascular disease caused by acute coronary occlusion, remains high in China [1]. Rapid revascularization through thrombolytic or interventional therapy as well as coronary artery bypass graft surgery is the best way to save patients' lives and improve the prognosis of AMI patients. However, cardiac dysfunction, heart failure and arrhythmia still relate to poor outcome of AMI patients [2]. It is known that sympathetic hyperactivation often occurs during the recovery period after AMI [3] and is a key factor of cardiac and electronic remodeling post AMI [4,5]. According to literature, under the premise of standardized treatment after AMI, the incidence of heart failure within 1 year is about 8%, and the incidence of heart failure within 5 years is about 20% post AMI [6]. Ventricular arrhythmias, including ventricular fibrillation, ventricular tachycardia, and ventricular premature beats, are common arrhythmias after AMI. Significant arrhythmias can also lead to cardiac dysfunction and even death during the disease process post AMI [7,8].

It is known that renal denervation (RDN), through interventional operation could damage the renal sympathetic nerve inhibit the renin-angiotensin-aldosterone system (RAAS) and reduce sympathetic nerve activity [9]. In the early clinical practice, RDN was mainly used in the treatment of refractory hypertension, and subsequent studies found that RDN was beneficial on alleviating, heart failure, pulmonary hypertension, arrhythmia, etc. [10]. The previous research of our research group also found that RDN can improve the cardiac function and exercise tolerance of patients with heart failure [11]. Therefore, RDN may also have potential therapeutic effect on cardiac function and myocardial remodeling after myocardial infarction. To date, there are no clinical studies exploring the effects of RDN in improving cardiac function in patients with AMI. In this prospective randomized controlled study, we evaluated the effects of RDN was used to treat AMI for the first time, with the aim of observing the effects of RDN on cardiac function in AMI patients after percutaneous coronary intervention (PCI).

2. Methods

2.1. Patient selection

This is a single-centre prospective randomized controlled study (Clinical Research Registration Number: ChiCTR1800020362). The inclusion criteria were as follows: 1.patients with acute ST-segment elevation myocardial infarction hospitalized in our hospital from January 2019 to December 2020 who were stable for 4 weeks after emergency PCI(no clinical symptoms of heart failure, no angina), and 2.age between 18 and 85 years old. The exclusion criteria were as follows: 1.a history of renal artery stenosis or imaging evidence showing renal artery stenosis; 2.a GFR<45 ml/min/1.73 m^2; 3.a history of old myocardial infarction; 4.a clear history of malignant ventricular arrhythmia; 5.severe heart valve disease; 6.pregnancy or a plan to become pregnant during the study period; 7.plans to undergo coronary artery bypass graft (CABG) or PCI again in the near future; and 8.adverse cardiac events (another myocardial infarction, angina pectoris, heart failure) during hospitalization. The flow chart of this trial is provided in Fig. 1.

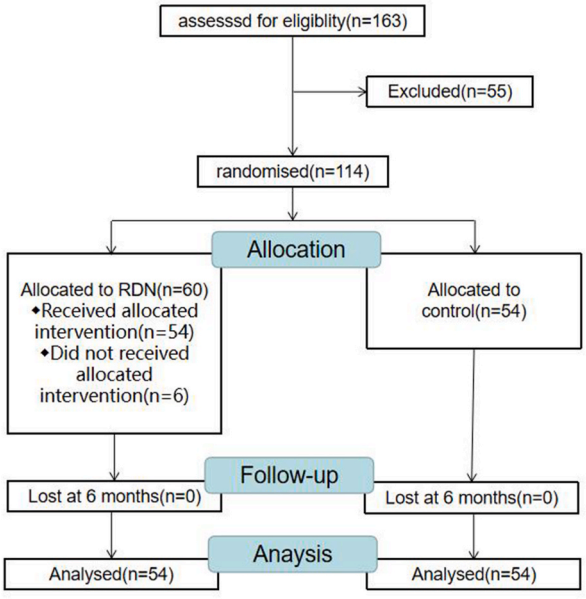

Fig. 1. Trial flow chart.

2.2. Intervention

Screening patients immediately after AMI and signing informed consent form 4 weeks after AMI. After receiving information on the study and signing the informed consent, all patients who met the inclusion criteria were randomly divided into two groups (control group and RDN group) at 1:1 ratio by random envelope method. All patients were treated with standard myocardial infarction drug therapy, including dual antiplatelet therapy, anticoagulation or IIb/IIIa receptor blockers if necessary, statin therapy, and angiotensin-converting enzyme inhibitors (ACEIs)/angiotensin receptor blockers (ARBs) and beta-blockers if there were no contraindications.

Patients in the RDN group underwent renal denervation via radiofrequency ablation at 4 weeks after the PCI on top of standard therapy. The rational for choosing the RDN timing are as follows: after myocardial infarction and reperfusion, some myocardium will experience myocardial stunning, which might disappear after 4–6 weeks. Therefore, the guidelines recommend that the timing of ICD implantation in patients with severe heart failure after myocardial infarction should also be 6 weeks after myocardial infarction. ICD implantation is to prevent the occurrence of malignant arrhythmias after myocardial infarction, and RDN treatment can inhibit RASS and sympathetic system, contribute to the attenuation of myocardial remodeling. Therefore, it might be helpful to perform RDN 2 weeks earlier than ICD post AMI, so we decided to carry out RDN treatment at 4 weeks post AMI in this study.

Patients with old myocardial infarction was excluded in this study, since they might already have long-standing necrotic myocardium and myocardial fibrosis, which might underestimate the potential beneficial impact of RDN on patients with relative "fresh" AMI.RDN was performed after adequate antiplatelet aggregation, and intraoperative intravenous unfractionated heparin at 50 U/kg was injected. During the operation, the skin of the right groin was prepared and disinfected, the femoral artery was punctured, and a 7F vascular sheath was placed. Then, left and right renal arteriography was performed with a 7F guiding catheter. After confirming that there was no renal artery stenosis or other lesions, a left internal mammary artery (LIMA) catheter was positioned at the opening of the left and right renal arteries, and a 5F saline-perfused radiofrequency ablation catheter (HDA5C090TC, Shanghai Wisegain Medical Devices Co., LTD) was used to perform radiofrequency ablation of the left and right renal arteries. Circular ablation of the trunk and branches was performed in the left and right renal arteries at 43° Celsius in the temperature-controlled mode. Each point was ablated for 60 s, and the distance between each ablation point was approximately 0.5 cm. Renal arteriography was reviewed after the operation.

Table 1
Clinical baseline data of the two groups of patients (week 4 after AMI).

Items	RDN group (n = 54)	Control group (n = 54)	*P*
Age (Mean ± SD, year)	63.50 ± 11.43	64.22 ± 11.85	0.596
Male [n (%)]	45 (83.33)	44 (81.48)	0.800
Systolic pressure (Mean ± SD, mmHg)	124.5 ± 31.1	118.8 ± 23.0	0.313
Diastolic pressure (Mean ± SD, mmHg)	75.3 ± 16.8	74.4 ± 15.3	0.631
Heart rate (Mean ± SD, bpm)	82.4 ± 16.2	79.5 ± 15.5	0.411
Anterior myocardial infarction [n (%)]	27 (50.00)	25 (46.30)	0.799
Infarcted vessel [n (%)]			
LAD	29 (53.70)	26 (48.15)	0.651
LCX	10 (18.52)	13 (24.07)	0.584
RCA	15 (27.78)	15 (27.78)	1
Risk factors [n (%)]			
Hypertension	25 (46.30)	28 (51.86)	0.564
Diabetes mellitus	14 (25.93)	18 (33.33)	0.399
Hyperlipidemia	3 (5.56)	1 (1.85)	0.618
CVA [n (%)]	4 (7.41)	4 (7.41)	1.000
Smoking [n (%)]	32 (59.26)	31 (57.41)	0.845
Creatinine (Mean ± SD, μmoI/L)	95.30 ± 82.05	77.61 ± 29.11	0.10
Uric acid (Mean ± SD. mmol/L)	390.04 ± 113.79	387.04 ± 134.63	0.873
Total cholesterol (Mean ± SD, mmol/L)	5.18 ± l1.17	4.99 ± 1.35	0.450
Triglyceride (Mean ± SD, mol/L)	1.74 ± 2.05	1.96 ± 1.74	0.439
LDL (Mean ± SD, mmol/L)	3.51 ± 0.98	3.33 ± 0.91	0.659
HDL (Mean ± SD, mmol/L)	1.19 ± 0.44	1.07 ± 0.34	0.878
Hemoglobin (Mean ± SD, g/L)	137.31 ± 18.56	135.69 ± 16.65	0.127
Medication at baseline [n (%)]			
ACEI/ARB/ARIN	44 (81.5)	44 (81.5)	1
Maximum tolerable/standard dose	26 (48.1)	29 (53.7)	0.564
Beta blocker	45 (83.3)	44 (81.5)	0.800
Maximum tolerable/standard dose	24 (44.4)	27 (50.0)	0.563
Aldosterone receptor antagonist	16 (29.6)	15 (27.8)	0.832
Medication at 6 months [n (%)]			
ACEI/ARB/ARIN	46 (85.2)	48 (88.9)	0.567
Maximum tolerable/standard dose	31 (57.4)	33 (61.1)	0.695
Beta blocker	45 (83.3)	47 (87.0)	0.588
Maximum tolerable/standard dose	29 (53.7)	30 (55.6)	0.847
Aldosterone receptor antagonist	15 (27.8)	13 (24.1)	0.275

LAD:left anterior descending; LCX:Left circumflex; RCA:Right coronary artery; CVA, cerebrovascular accident; LDL, low density lipoprotein; HDL, high density lipoprotein.

2.3. Evaluation indicators

1) Cardiac function assessed by echocardiography at 4 weeks after PCI and at 6 months thereafter (primary endpoint);
2) Cardiopulmonary exercise testing (CPET), NYHA classification): evaluated at 4 weeks after PCI and at 6 months thereafter.
3) Heart rate variability analysis: 4 weeks after PCI and at 6 months thereafter.
4) Heart rate and blood pressure: The heart rate and blood pressure of patients were recorded at 4 weeks, 2 months, 3 months, 4 months, 5 months and 6 months after PCI;
5) Serum detection of biochemical indicators (renal function, C-reactive protein (CRP), B-type natriuretic peptide (BNP), troponin I) was performed at 4 weeks after PCI and at 6 months thereafter PCI
6) Cardiac adverse events: Cardiac adverse events (death, heart failure, myocardial infarction, etc.) were analyzed up to 6 months post PCI.

2.4. Statistical analysis

SPSS 22.0 statistical software was used for data processing. Measurement data are expressed as the mean ± standard deviation ($\overline{\chi}$ ±S). Measurement data with a normal distribution were compared by Student's T test or analysis of variance, and skewed measurement data were compared using the nonparametric Mann–Whitney *U* test. The enumeration data are expressed as the frequency or percentage, and compared using the $\chi 2$ test or Fisher's exact test. All tests were two sided, and $P < 0.05$ was considered indicative of statistical significance.

2.5. Sample size estimation

Referring to the study of Hanada K [12], taking the increase of left ventricular ejection fraction by 2.9% as the effective value, the mean difference test between the two groups was used according to $\alpha = 0.05$, inspection efficiency 1- $\beta = 0.95$, and according to the lost follow-up rate of 20%, the sample size was set around 100 cases.

3. Results

3.1. Baseline features of patients in the two groups

A total of 108 patients were included (n = 54 each group). There were no significant differences, including the levels of serum creatinine, uric acid, cholesterol, triglycerides, low-density lipoprotein, high-density lipoprotein or haemoglobin, at baseline between the two groups (all $P > 0.05$, Table 1).

3.2. Comparison on echocardiography-derived indicators at baseline and at 6 months post PCI between the two groups

Baseline indicators were similar between the two groups ($P > 0.05$). Compared with the control group, the left ventricular ejection fraction (LVEF), left ventricular internal end-systolic diameter (LVIDs), fractional shortening (FS), and left atrial end-systolic dimension (LADs) were significantly improved in the RDN group at 6 months post PCI (all $P < 0.05$) (Table 2).

Table 2
Effects of RDN on echocardiographic parameters in AMI patients after PCI.

Items	RDN group (n = 54)	Control group (n = 54)	*P*
LVEF (%)			
Baseline level	48.61 ± 6.12	48.83 ± 7.62	0,868
6 months	57.14 ± 6.78	47.89 ± 9.12	<0.001
LVIDd (mm)			
Baseline level	49.27 ± 4.66	50.12 ± 7.86	0.498
6 months	50.02 ± 6.14	52.36 ± 6.57	0.058
LVIDs (mm)			
Baseline level	34.15 ± 5.35	36.13 ± 5.54	0.061
6 months	34.26 ± 5.61	37.84 ± 7.21	0.005
LADs (mm)			
Baseline level	38.67 ± 4.52	39.33 ± 4.47	0.443
6 months	36.68 ± 5.17	39.24 ± 4.67	0.008
FS(%)			
Baseline level	30.36 ± 7.86	29.62 ± 7.08	0.660
6 months	30.82 ± 4.80	27.30 ± 6.95	0.003

LVEF, left ventricular ejection fraction; LVIDd, Left ventricular end diastolic diameter; LVIDs, Left ventricular end systolic diameter; LADs, Left atrial diameter; FS, fractional shortening.

3.3. The effect of RDN on clinical cardiac outcome in myocardial infarction patients after PCI

3.3.1. The effect of RDN on the New York Heart Association classification of myocardial infarction patients after PCI

New York Heart Association classification was similar at baseline and significantly improved in RDN group than in control group ($P < 0.05$) (Fig. 2).

3.3.2. Comparison on exercise tolerance (CPET)-derived indicators between the two groups at baseline and at 6 months post PCI

The cardiopulmonary exercise test results that at 6 months post PCI, VO_2max, metabolic equivalents (METs), peak heart rate, heart rate recovery at 3 min, 5 min, and at 8 min were significantly improved in the RDN group compared with the control group (all $P < 0.05$) (Fig. 3A and B).

3.4. Comparison on blood pressure and heart rate between the two groups

During the 6-month follow-up period, there was no significant difference in blood pressure or heart rate between the RDN group and the control group (all $P > 0.05$).

3.5. Cardiac adverse events during the 6 months follow up after PCI

During the 6-month follow-up, 2 patients in each group were hospitalized for heart failure; there were no other adverse cardiac events.

3.6. Heart rate variability comparison at baseline and at 6b months post PCI between the two groups

There was no significant difference in baseline HRV between the 2 groups (all $P > 0.05$). TRIIDX, SDNN, SDNNIDX, rMSSD and pNN50 were significantly higher in the RDN group than those in the control group (all $P < 0.05$)), as shown in Table 3.

3.7. Comparison on CRP, BNP and troponin I levels between the two groups at baseline and at 6 months after PCI

Baseline biomarkers were similar between the two groups (all $P > 0.05$). At 6 months post PCI, there were no significant differences in CRP and troponin I levels between the RDN group and the control group ($P > 0.05$). The BNP level was significantly lower in the RDN group compared with that in the control group ($P < 0.05$).

4. Discussion

This is the first clinical study evaluating the safety and efficacy of RDN in AMI-PCI patients. The results of this study show that RDN can significantly improve cardiac function in AMI-PCI patients. Through the analysis of HRV, we found that RDN can regulate autonomic nerve function, inhibit sympathetic nerve activity and restore sympathetic vagal balance in AMI-PCI patients.

Disorders of the RAAS and autonomic nervous systems are the main factors leading to cardiac dysfunction after AMI, and they are also important adverse factors affecting the prognosis post AMI [4,5,13,14]. RDN is an interventional procedure that damages the renal sympathetic efferent nerve by catheter or chemical ablation [15], which can inhibit the activity of the sympathetic nerve. The mechanism is not fully clear at present, RDN may induce the increase of the γ-aminobutyric acid (GABA) activity in the hypothalamic paraventricular nucleus, leading to the inhibition of the sympathetic nervous system [16]. At the same time, GABA can inhibit the RAAS system and reduce the level of Ang II in peripheral blood [17,18], which is beneficial in cardiovascular diseases. At present, RDN

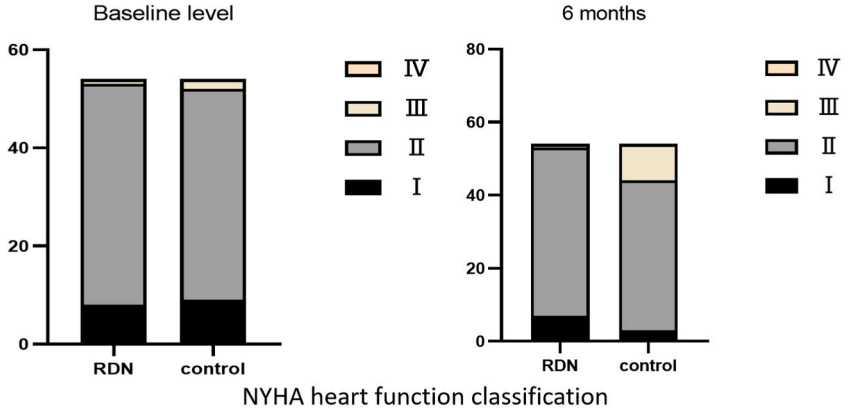

Fig. 2. NYHA heart function classification at baseline and 6 months after PCI.

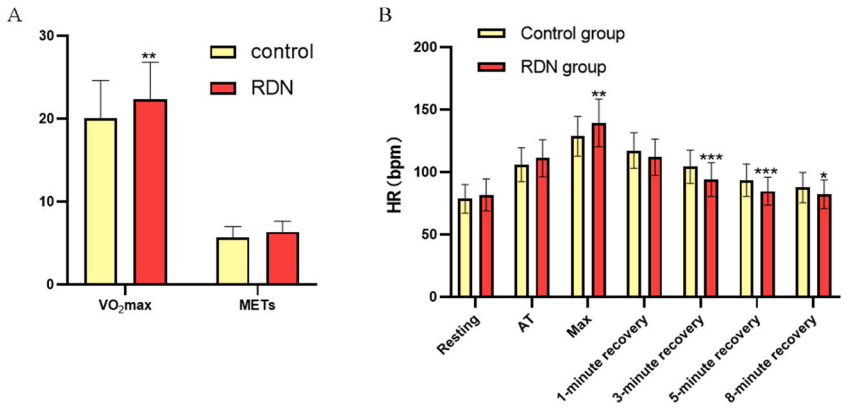

Fig. 3. AVO_2Max and MET between-group comparison at 6 months,
MET: metabolic equivalent
★★: P < 0.01
Fig. 3B: HR between-group comparison at 6 months
★: P < 0.05; ★★:P < 0.01; ★★★: P < 0.001.

Table 3
Effect of RDN on heart rate variability in AMI patients after PCI.

	Baseline level			6 months		
	RDN (n = 54)	Control (n = 54)	*P*	RDN (n = 54)	Control (n = 54)	*P*
NNs	76134.74 ± 28205.54	80371.13 ± 23972.23	0.402	78553.37 ± 23248.09	78472.24 ± 27390.13	0.987
Mean NN	804.30 ± 131.42	827.28 ± 109.28	0.325	853.56 ± 139.70	821.39 ± 111.87	0.189
SDNN	86.61 ± 36.05	94.46 ± 37.90	0.272	120.63 ± 42.05	96.09 ± 37.34	0.002
SDANN	67.48 ± 30.25	79.15 ± 31.69	0.053	93.93 ± 38.15	83.31 ± 33.96	0.130
SDNNIDX	45.04 ± 31.28	40.80 ± 26.43	0.448	61.85 ± 43.72	42.33 ± 26.85	0.006
rMSSD	45.78 ± 47.47	35.50 ± 35.46	0.205	67.85 ± 67.74	36.74 ± 39.78	0.004
pNN50%	11.19 ± 17.36	7.93 ± 14.00	0.286	17.98 ± 23.93	8.32 ± 14.66	0.013

NNs, normal-to-normal R–R intervals; Mean NN: mean normal-to-normal R–R intervals; SDNN, standard deviation of the normal-to-normal R–R intervals; SDANN, standard deviation of 5-min average of normal R–R intervals; rMSSD,root-mean square of differences between adjacent normal R–R interval; pNN5%0,percentage of adjacent NN intervals differing by more than 50 ms.

is widely used in diseases such as hypertension and heart failure [10,19]. Studies have confirmed that RDN can inhibit the inflammatory response, reduce myocardial fibrosis, improve cardiac function [11,20], and reduce arrhythmia in experimental AMI models [21,22] by reducing central sympathetic activity and regulating the IL-33/ST2 signaling pathway. Notably, reperfusion might further aggravate myocardial injury after PCI for AMI. Myocardial ischaemia-reperfusion can reduce the death of cardiomyocytes overall, but the area of myocardial injury caused by reperfusion injury can reach 50% of the total infarct area [23]. In the later stage of reperfusion, programmed cell death becomes the main mechanism of cardiomyocyte death. RDN immediately after reperfusion can reduce the NE content in the infarcted area and boundary area and reduce myocardial death [24]. At present, there is no clinical study on the effect of RDN on AMI patients after PCI. This is the first prospective randomized controlled clinical study to evaluate the impact of RDN cardiac function of AMI-PCI patients.

To evaluate the effect of RDN on cardiac function in AMI-PCI patients, New York Heart Association classification and echocardiography data were analyzed. At 6 months post PCI, patients in the RDN group had improved New York Heart Association classification and echocardiographic indicators of cardiac function compared with those in the control group. Myocardial infarction may affect the systolic and diastolic capacity of the myocardium, resulting in decreased LVEF and FS in patients. Higher LVEF and FS at 6 months post PCI in RDN group might be the underlying basis for the improved NYHA classification, our results are in line with previous findings [15,25]. Left ventricular myocardial remodeling [26] is an important pathological process leading to the development of heart failure. Previous studies have found that RDN can reduce LADs and left ventricular end-diastolic dimension (LVDd), resulting in reverse cardiac remodeling in patients with heart failure [27]. In this study, the left ventricular internal end-diastolic diameter (LVIDd), left ventricular end-systolic dimension (LVDs), and LADs were all smaller in the RDN group compared with those in the control group at 6 months post PCI, indicating RDN-related reverse cardiac remodeling, this might be another factor contributing to the improved clinical cardiac outcome including higher LVEF and lower NYHA classification post RDN.

Heart failure patients often have decreased exercise tolerance [28]. To evaluate the effect of RDN on exercise tolerance in AMI-PCI patients, CPET was performed at baseline and at 6 months post PCI. Previous studies have found that RDN can increase the 6-min walking distance and improve exercise tolerance in patients with heart failure [27,29]. CPET-derived VO2max, METs and Max HR can represent the reserve capacity of patients' cardiopulmonary function, our results showed that above indicators were significantly

improved after RDN intervention, suggesting that patients' exercise capacity was significantly improved at 6 months post RDN. In addition, the rate of heart rate recovery in the RDN group was improved after exercise compared with that in the control group. On the one hand, the improvement in exercise tolerance may be related to the improvement in cardiac function; on the other hand, these effects might relate to inhibited sympathetic nerves and restored sympathetic-vagal balance post RDN in AMI-PCI patients [15,30–32].

It is necessary to maintain stable blood pressure for patients to increase myocardial perfusion after AMI [33], RDN can reduce blood pressure and heart rate in patients with refractory hypertension [34,35], which may be harmful for AMI patients. Fortunately, heart rate or blood pressure were not affected by RDN during the 6 months follow-up in this study, these results were similar as previous reports on nonhypertensive patients post RDN [36]. In addition, peripheral blood BNP was significantly lower at 6 months post PCI in RDN group, which is sure another important evidence of the beneficial effects of RDN in AMI-PCI patients.

Holter-ECG examination was performed in our patients at 4 weeks and 6 months after PCI. After AMI, abnormal HRV occurs due to an increase in sympathetic activity and a decrease in vagus nerve tension [37,38]. TRIIDX and SDNN are usually used to evaluate autonomic nerve function and the degree of damage in patients. An SDNN<100 ms is considered to be a medium-high risk factor for autonomic nerve dysfunction [39,40], and studies have shown that SDNN is negatively correlated with the prognosis of AMI patients [41,42]. In our study, the baseline SDNN level of the two groups of patients was less than 100 ms, suggesting that both groups had different degrees of autonomic dysfunction. The SDNN level in the RDN group was significantly higher at 6 months than at baseline, while that in the control group was not. There were obvious changes, which meant that the autonomic nerve function of the patients in the RDN group had recovered significantly. SDANN can be used to assess sympathetic functional status, which is negatively correlated with sympathetic activity [43]. In this study, SDANN in the RDN group was increased at 6 months compared with that in the control group, but the difference was not significant, possibly due to intervention with β-blockers and other drugs. rMSSD and pNN50% can be used to assess the sensitivity of the vagus nerve to stimulation and are positively correlated with vagal tone [44]. Previous studies have shown that low values of vagus nerve-related indicators (rMSSD and pNN50%) indicate an increased risk of arrhythmia [45,46]. In our study, RDN intervention significantly improved these indicators. This finding is similar to previous studies showing similar effects of RDN on non-AMI patients [47,48]. Our study thus hints that RDN can restore the sympathetic-vagal balance in AMI-PCI patients, which may contribute to improving cardic function post RDN in AMI-PCI patients.

5. Study limitations

In this study, optimal medical therapy for AMI patients were not achieved and all relevant medication was underused, ACEI/ARB/ARNI and beta blockers were applied to around 80% of our patients, aldosterone antagonist was only applied to less than 30% of our patients, this was reflected by the NYHA II-III status in the majority of patients in the control group, cautions thus need to be recalled when interpreting the results of this study, future studies are needed to validate current results among AMI patients receiving optimal medical therapy.

6. Conclusions

Our research results show for the first time that RDN is safe and associated with beneficial effects on improving cardiac function, exercise capacity and reverse cardiac remodeling in AMI-PCI patients, possibly through the inhibition of sympathetic nerve activity and restoration of the sympathetic-vagus balance in AMI-PCI patients.

Funding

This work was supported by The Shanghai Key Medical Specialties Construction Project (ZK2019A11); Clinical Advantage Discipline of Health System of Putuo District in Shanghai (2019ysxk01); Medical innovation research project of "scientific and technological innovation action plan" (21Y11909600); Young Elite Scientists Sponsorship Program by CAST (QNRC2-B03); Shanghai Municipal Health and Health Commission Health Industry Clinical Research Project (201840247); Shanghai Municipal Health and Health Commission Health Industry Clinical Research Project (20214Y0494); Personnel training plan of Putuo Hospital (2022-RCJC-01).

Ethic statement

This study was approved by Ethics Committee of Shanghai Putuo District Central Hospital (Putuo Hospital Affiliated to Shanghai University of Traditional Chinese Medicine) (Approval number: PTEC-A-2018-46-1). The study was conducted according to established ethical guidelines and informed consent obtained from the participants.

Author contribution statement

ZJ.L conceived and designed the experiments; JQ.G, JJ.F, CH.Y, HG.J & RQ.H performed the experiments; SX.H, W.Y & M.L analyzed and interpreted the data; YL.X &J.Y contributed reagents, materials, analysis tools or data; JQ.G wrote the paper.

Author contribution statement

Jun-Qing Gao: performed the experiments; wrote the paper <p>.
You-Long Xu and Jian Ye: contributed reagents, materials, analysis tools or data <p>.
Shu-Xin Hou, Wei Yang and Min Li: analyzed and interpreted the data <p>.
Jing-Jing Fa, Cheng-Hao Yang, Hui-Gen Jin and Rui-Qing He: performed the experiments <p>.
Zongjun Liu: conceived and designed the experiments <p>.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e17591.

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